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ABSTRACT

The focus of this study was to portray the ideas that students with four years experience in learning physics developed in regard to the second law of thermodynamics. Data were obtained through 34 clinical interviews with grade 10 students. An analysis of student arguments revealed deeply rooted difficulties in using concepts that were learned in school. There appears to be a strong tendency for students to rely on everyday knowledge rather than knowledge obtained in class. Moreover, the second law of thermodynamics as a topic of science instruction has been almost totally neglected, especially in the lower grades. Most students, therefore, do not learn a law that provides a very deep insight into the way nature works. A basic understanding of the principle of energy conservation requires a basic understanding of the principle of energy degradation. Results of this study indicated that basic aspects of the second law of thermodynamics are not too difficult to be learned in the lower grades, but that such learning will only be possible when students are provided with a sound conceptual framework in the areas of heat, temperature, energy, and the particle model.
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STUDENTS' CONCEPTIONS OF BASIC IDEAS OF THE SECOND LAW OF THERMODYNAMICS

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Abstract

34 clinical interviews with grade 10 students (about 15 to 16 years old) were carried out. The study is based on a qualitative research approach. The main focus of attention is at description of the ideas possessed by students with four years of experience in learning physics developed in this field.

The educational importance of the study may be seen from two angles. Firstly in a general way. The careful analysis of students' argument reveals deep-rooted difficulties in making use of the concepts and models taught in school. Secondly the main focus of attention concerns the second law of thermodynamics as a topic of science instruction. So far this law has been almost totally neglected, especially in lower grades. Most students therefore do not learn a law which provides a very deep insight into the way "nature works". Furthermore, they do not learn a principle necessary for an understanding of the energy concept which is given considerable attention in science instruction - for several good reasons.

The results of the study confirm findings of other studies concerning students' severe difficulties in learning the energy concept, the particle model and the distinction between heat and temperature. It seems very unlikely that this will provide a basis for the second law. The study also reveals that during the four years of physics instruction our students received, ideas concerning the second law were not significantly developed. We conclude from these results that it is not valuable to simply enrich traditional physics instruction by teaching aspects of the second law, but that an approach must be designed which provides guidance concerning these aspects within a totally new framework, and which can also be applied to the concepts of heat, temperature and energy as well as to the particle model.

1. INTRODUCTORY REMARKS ON THE SIGNIFICANCE OF THE SECOND LAW OF THERMODYNAMICS IN SCIENCE INSTRUCTION IN LOWER GRADES

"Once or twice I have asked gatherings of people who - by the standards of traditional culture - are thought to be highly educated: How many of them could describe the second law of thermodynamics? The result was cold: It was negative. Yet I was asking something which is about the equivalent of: Have you read a work of Shakespeare?" (C.P. Snow, cited in Marx, 1983).

It is interesting that not only the highly educated public appears to be ignorant of the second law but school science too - at least in lower grades. In science classrooms this law is given only little attention, in lower grades (i.e. for students in the age level of 12 to 16) there is almost no mention of any basic idea of this law - although this law undoubtedly is at least just as important as the first law of thermodynamics (the principle of energy conservation) which has been given a great deal of attention in science classrooms for some 20 years.

The main reason for the reserve of school science towards the second law appears to be the conviction that this law is too difficult for students to understand, especially in lower grades. We believe that this is not the case. We are convinced that even students in lower grades are able to understand the basic ideas of the second law presented in fig. 1 to a considerable extent. Our aims in teaching these basic ideas are given in fig. 2.

In the past 10 to 15 years a number of new approaches to the second law - also for students in lower grades - have been developed and (sometimes) evaluated in school practice. But substantial research on students' learning in this field is still missing. Whereas there are numerous studies on students' conceptions and students' conceptual change available in many fields of science, the field of the second law has been neglected. There are some studies on students' conceptions of energy degradation (see e.g. Solomon, Black, 1983; Brook, Driver, 1984). There are also studies on students' ideas of "order-disorder-information" (see Schaefer, 1983) and Piagetian studies on the idea of chance (see the summary of Bliss, 1978). Further, in

studies on thermal equilibrium, heat conduction and latent heat aspects of the basic ideas of the second law are investigated (see Shayer, Wylam, 1981; Wiesner, Stengl, 1984; Harnaes, 1985; Tomasini, Balandi, 1987; Wiser, 1987). But in general, we know only very little about students' conceptions here.

Irreversibility and asymmetry in nature

All "real" processes take place by themselves in one direction only. Heat travels by itself from a hot body to a cold one. There is no cyclical heat engine which does work except at the cost of cooling down a heat reservoir.

Energy degradation

In every process which occurs in the real world energy loses value, i. e. is degraded.

Tendency towards ...

... even distribution of matter and energy, ... disorder, ... ignorance (i. e. loss of information).

The destructive and the constructive aspects of the 2nd law
Usually only (or mainly) the "destructive" aspect of the 2nd law is emphasized. But there is also a "constructive" aspect. The creation of new structures does not occur "in opposition to" the 2nd law but because of it. Atkins (1983) stated this idea very clearly: "The very nature of nature is decay but decay drives creation".

Fig. 1: Qualitative ideas of the second law

(1) Insight into the "nature of nature"

The ideas provide a deep insight into the "way nature works". Students acquire access to fundamental principles of science.

(2) Understanding of energy supply issues

Undoubtedly understanding of problems of energy supply in society requires a sound insight into the above basic ideas of the second law, especially energy degradation.

(3) Understanding of the energy concept

Not even the scientific concept of energy appears to be understandable without the aspect of energy degradation. The aspect of energy conservation seems to contradict experiences in the real world where degradation is the dominant impression. Energy conservation and energy degradation therefore both have to be regarded from the very start of teaching about energy (see Duit, 1983b).

Fig. 2: Aims of teaching basic ideas of the second law

2. AIMS, DESIGN AND PROCEDURE OF THE STUDY ON STUDENTS' CONCEPTIONS OF BASIC IDEAS OF THE SECOND LAW

2.1 Aims

We view the study presented in this paper as a preliminary step in the direction of the above deficient field. It investigates students' conceptions and not conceptual change. Furthermore, it does not deal with all the basic aspects presented in fig. 1. It focuses on the irreversibility aspect and also pays some attention to energy degradation and the tendency towards disorder.

We chose the following approach to investigate students' conceptions in the above mentioned field. We wanted to find out whether students learn aspects of the second law within traditional physics instruction incidentally where these aspects were not given (much) attention. We also wanted to find out whether the conceptions students gained through several years of traditional physics instruction may form a fruitful starting point for teaching and learning the basic aspects presented in fig. 1. In other words, we are aiming at information which may be used to design new teaching and learning approaches for basic aspects of the second law.

2.2 The sample of the study

To meet these aims we interviewed 34 grade 10 students (i.e. about 15 to 16 years old) at the end of lower secondary level. The students had been taught physics for four years (two periods a week) in a German grammar school which is the highest level in our streamed school system. The physics teaching which the 34 students had received covered the traditional themes. The concepts of heat, temperature and energy as well as the particle model (which play an important role in our study) were given considerable attention in the four years of physics instruction our students received. Basic aspects of the second law as presented in fig. 1 were not taught, at least not explicitly. The 34 students are from 9 classes in 7 schools in order to avoid class and school effects. 15 of them were female, 19 male. They

were chosen randomly. As the syllabus for all schools was the same the students covered more or less the same syllabus in physics.

2.3 The interview method

The method of clinical interview was employed. The interviews were carried out by the two authors of this paper, most of them by S. Kesidou. Students were presented with the situations briefly described below (for more details see the appendix). The situations were sketched on cards. The tools shown on the cards (e.g. a piece of metal, a beaker filled with water, a pendulum) were also presented to the students but experiments were not carried out. The interview followed an interview guide (see the abbreviated version in the appendix). But the interviewer was given the possibility to follow students' ideas if she/he had the impression that this would be fruitful. The interviews were recorded and transcribed.

As is usually the case in clinical interviews we started with rather open questions. The main intention of the interviewer was to help students to develop their own ideas. But two types of intervention were used. At specific places in the interview we reminded students of concepts and models taught in physics instruction (e.g. the meaning of the concepts heat and energy in physics or the particle model) if they had not used them so far. We asked for explanations using these concepts and models. We further tried to investigate the consistency of students' explanations in different parts of the interview. We therefore confronted students with answers they had given before.

2.4 A brief sketch of the interview's problems

The first three problems of the interview deal with heat exchange processes (seen from the physics point of view), i.e. with processes where two bodies of different temperatures are brought into contact. The focus is on the frameworks used by the students to explain the process of temperature equalization. Particular emphasis is given to the problem of whether the tem-

perature equalization processes may run backwards. Problems 1 and 2 investigate heat exchange between two different materials (water and metal) when the metal is cooled (1) and when the water is cooled (2). Problem 3 discusses heat exchange between two bodies of the same material (two similar metal plates). In pilot studies a considerable number of students were of the opinion that temperature differences may occur due to the qualities of the different materials involved. Problem 3 is designed to control the influence of the materials of the bodies in contact on students answers.

Problem 1: A piece of metal is heated to 80°C. It then is put into water at 20°C. The temperature equalization process is discussed. Students are asked for the meaning of the terms heat and temperature they use to describe the process. Students are then asked whether it is possible that after equalization a temperature difference may occur, whether the piece of metal may have a temperature of 15°C after a while and the water 29°C or whether the process may be reversed, i.e. with the piece of metal at 40°C again after a while, whereas the temperature of the water returns to 25°C.

Problem 2: A cold piece of metal (20°C) is put into hot water (80°C). Basically the same questions are asked as in problem 1. If there are contradictions between students' answers to problems 1 and 2 the interviewer asks for an explanation.

Problem 3: Two similar metal plates (20°C and 80°C) are brought into contact. Here basically the same questions as in problems 1 and 2 are asked. Students are reminded of contradictions in their answers if there are any.

Problem 4: The problem of the possible occurrence of temperature differences in daily life is discussed. The situation "cold tea becomes hot by itself after it has cooled down" is presented. Is this process possible? Why / why not?

Problem 5: Two equal amounts of water and alcohol (initially at 20°C) are heated with identical burners. The alcohol reaches a temperature of 30°C after two minutes, it takes four minutes for the water to reach this temperature. Discussions as to this is so take place. Students' use of the concepts of heat, temperature and energy to explain this are also investigated (e.g. has the water at the end received or has it stored more energy than the alcohol?). Then students are confronted with the situation of water and alcohol both at 30°C which are brought into contact. Is there any change in temperature? We investigated whether students believe that temperature differences may occur due to the fact that water possesses more energy, and that temperature differences may occur because water transfers energy to the alcohol.

Problem 6: In the last problem which is devoted to students' conceptions of temperature equalization processes, a standard version of the second law in many textbooks is presented to students: "Heat never travels by itself from something cold to something hot". We investigated how students try to make sense of this sentence.

Problem 7: In order to investigate students' conceptions of irreversibility in another area we discuss whether a pendulum may start swinging by itself, i.e. by cooling the surroundings. The discussion here is also used to discover students' conceptions of energy, forms of energy and energy transformation. In particular students' ideas of transformation between heat energy and kinetic (motion) energy are investigated.

Problem 8: The concluding problem of the interview was to get a first insight into whether students are aware that all processes around them take place by themselves in one direction only, i.e. that all processes in the real world are irreversible.

2.5 On the "nature" of the study

The study is deliberately based on a constructivistic framework as, for instance, outlined by Driver (1989). It is qualitative in nature not quantitative. It follows the tradition of interpretive research (see Erickson, 1986), i.e. a tradition which Gilbert and Watts (1983) call "verstehen" tradition, an allusion to German hermeneutics approaches which date back to Dilthey. Its main aspects resemble Marton's (1981) phenomenography.

We try to make sense of students reactions to the interview situations, we try to understand their responses from their point of view rather than employing the physics view as the main or even the only frame of reference. In order to avoid misunderstandings we want to point out that this does not mean that the physics view does not play a role in our study. As has been mentioned already (see 1.) we think that this view is very valuable and worth knowing for students. But what we are looking for in our interviews are ways of facilitating students' access to this view, i.e. we want to investigate starting points for conceptual change, approaches which will guide students from their own views to the physics one.

2.6 On the development of the interview

The interpretive position has important consequences for the way we proceeded. When we designed the study presented here we started from a set of problems used in physics textbooks as examples of the aspects of the second law we were focusing on (see 2.1). On the basis of the study of the relevant literature and on the basis of our experiences with research on students' conceptions in general, we developed preliminary ideas concerning the frameworks students might use to explain the processes the physicists explain by aspects of the second law. A first version of an interview resulted from these considerations and we tried it with 7 students. From these findings we revised and further developed our ideas of students' conceptions. A second version of an interview was carried out with 14 students (see findings from this part of the study in Duit, Kesidou, 1988). The two pilot studies resulted in the present version of the interview and in a fairly developed amount of knowledge concerning students' conceptions.

It is the major problem of interpretive studies to get to know students conceptions despite the hermeneutic circle, i.e. despite the fact that our knowledge of students' conceptions is dependent on our constructions which are based on our conceptions (see Johansson et al, 1985; Jung, 1987). We think that our strategy of various steps which enabled us to revise our constructions of students' conceptions in a "spiral" way have considerably enlarged the validity of our interpretations.

2.7 On the interpretation process

The findings presented in the following chapter are the results of a complex interpretation process. As has been mentioned before we embarked upon this process with the physics point of view and with fairly developed ideas of students' conceptions. These initial ideas were used to interpret students' responses. On the basis of this, the initial ideas were further elaborated and categories were worked out. Thorough descriptions of the categories facilitated an assessment of all interviews. The

scoring process did not only provide quantitative aspects, but also allowed us to analyze students' consistency in the same categories concerning different problems. The categories and students' responses in the interview, form the basis of the interpretations presented in the following chapter. We have followed a strategy expounded by Gilbert and Watts (1983).

It may be surprising that students' responses still play a directly important role in the interpretation process, although the responses are already scored according to the categories. It has to be kept in mind that this scoring process reduces data to aspects which are in some way objective, i.e. to categories which may be described in such a way that different scorers agree in the scoring process. When students, for instance, use a term like energy, it is easy to put such an answer into a reference category (e.g. "use of the term energy"). But students put into this category may have had different ideas in mind when they used this word. It is therefore necessary to go back to students' responses in order to ascertain what they meant by a certain term from the way they used it. Svensson (1985) argues in favor of such contextual analysis of the data, because the "same" specific data may have totally different meanings in different contexts.

What has been rather briefly sketched here is a certain "weakness" of studies carried out within an interpretive frame. We are aware of the limitations of the interpretations we present in the following chapter. We know that we present our constructions of students' conceptions. But we try to provide some information (e.g. by giving examples from students responses) which allow readers to consider whether they would come to the same conclusions concerning students' conceptions. Of course, such attempts are limited in a relative short paper like this one. Further, there is the problem of translating students' answers from German to English. Our translations are interpretations. Hence the examples from students' responses are not "objective" data but in some way "subjective".

3. FINDINGS OF THE STUDY

Main findings of our study are summarized in the following. We try to portray the frameworks employed by our students most frequently to make sense of the phenomena presented in the interview. The first five paragraphs (3.1 to 3.5) deal mainly with knowledge which is necessary for an understanding of aspects of the second law. The concluding paragraph (3.6) summarizes our findings concerning the aspect of irreversibility.

3.1 Differentiation between heat and temperature

It is well known from many studies that students have severe difficulties in differentiating adequately between heat and temperature. This also holds for students at a quite advanced level (see e.g. Tiberghien, 1983; Brook et al, 1984). In our study we recognized similar difficulties among our students who had been taught the physics conceptions quite intensively.

When we asked students to explain the meaning of heat and temperature and to describe what heat and temperature have to do with one another (see problem 1.2 in the appendix) we got the following results. The number of students who gave particular responses is given in brackets. The total number of students was 34.

What is heat?

energy (12)/ heat energy (3)/ energy may be gained by heat (2)
temperature (4)/ high temperature (4)
sense impression (4)/ state of being hot (2)
movement of particles (5)

What is temperature?

amount of energy (5)/ energy (4)
heat (3)/ plus, minus (2)
measure or unit of heat (9)/ degree (5)/ measurable quantity (4)
speed of particles (3)

It is obvious that temperature is viewed by the majority of our students as a measurable thermal quantity. About 70 % of descriptions of what temperature means fall in this category. When asked to explain what heat and temperature have to do with one another 58 % mentioned that temperature measures heat. That heat

(seen from the physics point of view) is also a measurable quantity is not mirrored by students responses.

3.2 Intensity and extensity - frameworks to explain thermal processes

The findings presented in 3.1 provide an initial, albeit superficial view of students' distinctions between heat and temperature. They are based on students' responses when they were asked to describe what these terms meant for them. Students' explanations of thermal processes in other problems used in the interview allow a much more "in depth" view of these distinctions. In the following we shall outline general frameworks used by our students when they explained the phenomena presented in the interview.

To ease an understanding of students' frameworks as presented below, the physics view of heat and temperature will be briefly summarized. First of all, the distinction between extensive and intensive quantities as they are used here will be explained. Extensive quantities may be viewed as analogous to substances or in other words one may speak of amounts of these quantities. If a system contains a certain amount of such a quantity and another amount of it is added to the system, then the total amount of this quantity is the sum of the previous amount and of the amount added. This is different for intensive quantities. They may not be viewed as substances. If two systems with the same value for a specific intensive quantity are put together, the value of the intensive quantities does not increase but stays the same. In short: Extensive quantities are the ones where it makes sense to ask "how much" is available whereas for intensive quantities the question "how strong" or "how high" is reasonable.

Heat is the form of energy which is transported from one system to another due to temperature differences. Heat is an extensive quantity. If a specific amount of heat (Q_1) is transported and if this is followed by another amount of heat (Q_2) the total amount of heat transported is $Q_1 + Q_2$. Temperature is, however,

an intensive quantity. If two bodies with temperature T are brought into contact then the temperature of the two bodies is still T . This distinction between heat and temperature in the framework of extensity and intensity will be used in the following as background to students' attempts to make sense of thermal processes.

3.2.1 Heat as intensity and temperature as "degree" of heat

As has been mentioned in section 3.1 it is a frequent finding that students do not make an adequate distinction between heat and temperature that they appear to conceptualize only one thermal quantity, heat, and temperature being simply the quantification of heat. Seen within the intensity - extensity framework it is interesting to find a considerable number of students who view heat as an intensive quantity, at least in some of their responses.

In problem 4 students were asked whether a cup of tea or the room around it (both at the same temperatures) have the same heat. More than 50 % of the students asked answered that the cup of tea and the room have the same heat. One student gave this explanation:

They possess the same heat, the heat which is present everywhere.

Problem 5.1 provides further support for the students' view discussed here. Equal amounts of water and alcohol (both at 20°C) are heated by identical burners. The alcohol reaches 30°C after 2 minutes, water after 4 minutes. When asked which liquid received more heat, 15 out of 34 students (i.e. 44 %) did not see that the water received more heat than the alcohol. Even after the intervention of the interviewer who pointed to the fact that the water was heated for a longer time 7 students still thought that both received the same heat. Students explanations may illustrate the interpretation given here, namely that students view heat not as an extensive but as an intensive quantity:

The liquids have been heated with the same temperature/ with equally hot flames/ with the same burner. But water received heat for a longer time. Both liquids are at 30° C.

After the intervention of the interviewer (who remarked that water was heated for a longer time) some students said that water received more heat but they did not accept that water then contains more heat than alcohol. Here is a passage of an interview to illustrate this (I: Interviewer, S: Student).

I: What do you think, has one of the liquids received more heat?

S: No, more heat? Not really. If the burners are equal, then it is not possible that more heat was given.

I: But it was heated for a longer time.

S: It needs more heat to become hot.

I: Hence it received more heat?

S: That is right, indeed. Received heat a longer time, Ok, then it is right.

I: That means it now has more heat than the alcohol?

S: No, I do not think so.

I: But it received more heat.

S: No, I don't think it should have more heat.

We see two possible ways of interpreting the student's answers.

(a) The student switches in his answer from an intensive view of heat to an extensive one and back to an intensive one. (b) The student understands also "more heat" in an intensive framework, i.e. with more heat he only means heat (viewed as intensity) applied for a longer time and not something that has amount (i.e. is substancelike).

3.2.2 Heat as a general cause of temperature rise

It is a very valuable everyday schema that the effect is proportional to the cause and inversely to what prevents it (resistance). A number of students also appear to employ this schema to explain thermal processes. Often such a schema is based on the intensity view of heat as outlined in the previous paragraph. On the basis of such a schema it is obvious for the students why bodies of equal masses but of different materials reach different temperatures when they are heated with the same burners: some materials are difficult to heat, they are more resistant to heating. From this point of view there is no need for

the physics concepts heat and temperature and hence no need for the physics distinction between heat and temperature.

Furthermore, the cause-effect framework as outlined above does not demand a thinking in heat balances, i.e. it is not necessary within this framework to view heat as something which is transported from one body to another. Students who argued according to the cause-effect framework thought that heat is used to bring about a temperature rise. More heat is needed to cause a temperature rise in a body which is difficult to heat than in a body which is easy to heat. But this does not mean that both bodies have the same heat after the heating process because they have the same temperatures. The last sentence of the following passage from an interview may illustrate this way of thinking.

I: Has one of the liquids received more heat?

S: Well it took longer, hence there should be more heat, to warm it, should be a way, but may be ...

I: That means the alcohol has less heat than the water now?

S: No, both have the same temperatures.

I: But the water received more heat.

S: May be one can put it like this, more heat has been used to bring water to 30° C than to bring alcohol to 30° C. But the heat both came to is the same. Temperatures are equal, that means they have the same heat, but different heat was necessary to reach the same heat.

3.2.3 Heat as an extensive quantity, temperature as the amount of heat

It is not surprising that there are also students who viewed heat as an extensive quantity, i.e. viewed heat as something which is transported from one body to another (about 30 % of our students appear to have such an idea). But it is striking (from the physics point of view) that some students also viewed temperature as something which passes from one body to another, the degrees giving the amount of temperature transported.

In problem 1 students deal with the thermal interaction of two bodies of 20°C and 80°C. They are asked (problem 1.3) whether it may happen that at the end of the interaction the body which had an initial temperature of 80°C may reach 15°C (i.e. a temperature lower than the equalization temperature). The other body,

then, has a temperature above this point, namely 29°C . There are some students who argued that the sum of the temperature has to be the same at the beginning and the end of the interaction. Here is an example of the way these students argued.

S: If nothing can get away, then it must add up to 100°C .

I: What do you mean?

S: Now we have 44°C but initially it was 100°C , where have the other degrees gone if nothing gets lost?

There is a number of students who did not think that water has more heat than alcohol in problem 5.1 although it received more. In 3.5.1 we argued that this striking contradiction (seen from the physics point of view) did not exist for some students because they viewed heat as an intensive quantity, temperature being the means of measuring it. But there are other students who saw that there is a contradiction in that water did not have more heat although it had received more. They viewed heat as an extensive quantity and temperature as a measure of the amount of heat, i.e. as an extensive quantity too. They argued that the heat is the same at the end in both cases because the temperatures, i.e. from their point of view the amounts of heat, are also the same.

Some of the students solved the conflict by the idea that the water gave so much heat to the surroundings that at the end of the process it had the same heat as the alcohol - because temperatures are the same at the end.

In passing we shall briefly mention the fact that some students did not view temperature simply as amount of heat but as amount of heat per volume or per mass unit.

3.2.4 Heat, temperature - intensity and extensity

The careful in depth analysis of our students' attempts to explain the thermal processes presented in the interview reveals that only a small number of them gave explanations in a physics framework. In such a framework a clear distinction between an extensive energy-quantity heat and an intensive quantity temperature is necessary. Quite often it appears that no distinction

is made between heat and temperature in the extensity - intensity framework. Heat is frequently viewed as an intensity, temperature being the measure of this intensity or heat is viewed as extensity but temperature as extensity too, being the measure of the amount of heat. Our study therefore reconfirms findings of other studies which report that physics instruction has little influence on the everyday conceptions of heat and temperature. The importance of our findings with regard to irreversibility ideas will be discussed below (3.6).

3.3 The particle model and explanations of thermal processes

In 3.1 we presented students' attempts at describing the meaning of heat and temperature. Only a small number of students gave explanations in terms of the particle model. In total 7 out of 34 students (i.e. 21 %) gave explanations of this kind. There are answers to another question in problem 1, namely "what happens to a body if it is heated", which also indicate that explanations in terms of the particle model are seldom. Out of 25 students who were asked the mentioned question only 4 gave an explanation in the particle model on their own, a further 8 students used this model after the interviewer explicitly asked for an explanation in this model. But 13 students could give no particle explanation after the interviewer had asked them to do so.

There are some interesting conceptions among the small number of users of the particle model which appear to be worth mentioning here.

* In solid bodies particles move (due to the structure of these bodies) at low speed only, or do not move at all.

* It is much more difficult to set particles of solid bodies into motion than is the case with particles of liquids and gases. Argumentation of this kind sometimes appears to be based on ideas about the structure or the bonding in solids, liquids and gases, but also on the idea that the inertia of the particles is different in the three states of matter.

* 3 students are convinced that the particles will not move for ever but will slow down. They explain this by indicating that the particles are hindered in their movement or do not have enough space to oscillate. Inertia is also mentioned as a reason why particles slow down after a while.

* It is known from other studies that students explain the heating of a body by friction in this way: particles rub against one another and hence become warmer (Manthei, 1980). 4 of our students argued in a similar way. The following interview passage may illustrate this. It may also point to the mentioned inertia idea.

I: What is the temperature of the water after some time?

S: 20° C

I: And the temperature of the metal?

S: I think it is less than the temperature of the water.

I: Why is the temperature lower?

S: May be the molecules of the metal have more inertia than the ones of the water as time goes on.

I: What do you mean when you speak about inertia?

S: They move slowly. They are not inclined to be faster and hence produce greater heat or energy.

I: You just said they are not inclined to produce heat, the molecules.

S: The inclination to move faster, to dash along.

I: What does happen ...

S: Heat is produced.

I: How heat is produced?

S: The molecules rub against one another.

* The explanation of how heat is produced in the last sentence of the above citation transfers qualities of behavior in the macroscopic world to the microscopic one. In the macroscopic world heat is indeed produced by rubbing (i.e. by friction). There are some other findings of a similar kind concerning the transfer of qualities of the macroscopic world to the microscopic one. Some students, for instance, mentioned that particles expand when heated, others appear to hold the idea that heat is transferred from one particle to another in the process of heat conduction (similar findings are reported frequently in literature, see e.g. Rennström, 1987).

In brief, our students (like students in other comparable studies too) rarely made use of the particle model and if they did they mostly employed "alternative" conceptions, not the physics one. Often (as for instance in the case of the interview passage cited in this paragraph) there was a mix of physics ideas superficially learned in school and "alternative" conceptions (see the argumentation employing the term molecule above).

3.4 Energy conceptions

Students provide energy explanations for all problems posed in the interview. In the following, main findings will be summarized.

3.4.1 On the meaning of the term energy

In problem 7 it is discussed whether a pendulum may start oscillating by itself or not. An investigation of the meaning students attached to the term energy and the way they employed energy conceptions (or not) to explain the "natural" process, i.e. the process of the pendulum's oscillation coming to a rest is incorporated into this discussion.

When asked for the meaning of the word energy which students used in the explanations mentioned their answers fell into the following categories. The number of students is given in brackets.

What is energy?

force (12)/ a cause which brings about effects (9)
energy forms mentioned (3)/ phenomena mentioned (3)
energy is not lost (3)
something which is contained in bodies (2)

Similar findings concerning students' attempts to describe what energy is are frequently reported in literature. The pendulum problem which formed a framework for the description triggered slightly more "force" responses than is the case in other studies on the meaning of energy. Associations with electricity which were predominant in another study carried out in Germany (see Duit, 1983a) are not visible here.

3.4.2 Students' general energy frameworks

The aspects of transport, transformation, conservation and degradation (see Duit, 1986) are at the very center of the physics energy concept. When processes occur phenomena are usually changed (e.g. heat into motion, motion into heat, light into heat,....). Viewed in the physics energy framework, energy is transformed (i.e. energy changes form) and is (usually) transported from one place to another. Despite all these changes the amount of energy does not change (i.e. energy is conserved), but energy is degraded in that energy becomes less usable when processes occur.

The general framework which forms the basis for the energy ideas of most of our students is very different from the physics one. Briefly summarized energy was usually seen as something which brings about actions and effects. These effects of energy become visible by the change of intensive quantities (such as temperature or height). The change of extensive quantities also involved in the changes was often neglected. In problem 5.1, for instance, many students only regarded the temperature rise as an indication of the energy contained in the water and alcohol, and not the heat transferred to them. There is another important aspect of students' conceptualisation of energy within the "cause of actions and effect schema" discussed here. Actions and effects are hampered by resistances. If resistances are small little energy is necessary to overcome them, if they are big more energy is needed to reach the same state. When asked for the total energy at the end of the process, students' who thought according to the schema referred to only took the resulting effect into consideration and not the fact that different amounts of energy had been harnessed to achieve the effect: because the achieved effect is the same, the energy at the end is the same.

It is interesting that ideas of energy transport, transformation, conservation and degradation are mainly missing in this framework. Asked what all energy forms have in common most students answered that they all can cause actions and effects. They differ according to these students' answers in that they have different effects (e.g. heat energy heats, kinetic energy sets or keeps in motion). That one form of energy may be transformed into a different one (i.e. the physics view) was a view reflected by only 2 students (out of our 34). The physics view of energy conservation was also used very rarely. There was no student who used this idea unequivocally and consistently. The statement that energy is always conserved was made by many students, but it appears that it had only been learned by heart. Some students tried to make sense of this statement within the students' framework discussed here. They argued, for instance, that energy was not lost in processes because energy had brought about an effect, e.g. energy overcame resistances in processes

where friction was involved. The energy "conservation" idea of most of our students may be outlined in this way: energy is not lost but it is exhausted by bringing about an effect or an action. Here is a quote from an interview to illustrate this.

I: Does the pendulum's energy become less?

S: It should, because, if it still contained all energy it should have the force to swing more.

I: But what happens to the energy? Why does it become less? Is it lost?

S: No, energy can, as far as I know, not be lost, the principle of energy conservation says so, but ...

I: Where does it go to?

S: Where energy is used up in the pendulum, I do not know. Well, now I know. Gravity, the pendulum has to be pulled up again, energy is needed to do this. The pendulum is pulled down by gravity and it then has to work against gravity, so more energy is needed.

The idea that energy is used up in processes is quite a common idea. It is in fact at the very center of the energy frameworks of our students. When asked why a pendulum comes to rest after a while 10 students (out of 34) gave an explanation in which they explicitly employed the idea of energy being used up. The prevailing reasons for this energy loss were the force of gravity and air resistance (which have to be overcome). It is obvious, especially with regard to the "overcoming gravity" idea, that students are far from the physics conception of energy degradation.

3.4.3 Energy and heat

When students explained temperature equalization processes in problems 1 to 6 they frequently used the word energy. In general, heat and energy appear to be closely related. 17 out of our 34 students (i.e. 50 %), for instance, used the word energy when explaining what heat is (see 3.1). We asked 17 students explicitly for the connections between heat and energy. 10 of them viewed heat as a form of energy, 4 were even of the opinion that there is a force "behind" heat.

There are undoubtedly close connections between heat and energy. But it has to be kept in mind that this does not mean that a ma-

jority of our students viewed heat as a form of energy in the same way as the physicist does. Firstly, several students' answers reveal that sometimes energy is also viewed as an intensive quantity (compare 3.2.4). The students' energy framework outlined above prevails. In this framework the energy form heat energy causes heating, different energy forms have different effects. The idea of the transformation of heat energy into kinetic energy (or some other form of mechanical energy) and vice versa was not well developed. Most students had rather vague ideas here. When explaining why a pendulum comes to rest (problem 7.2.) only 3 students mentioned that kinetic energy is converted into heat energy in the surrounding air whereas 10 students pointed out that the motion energy is simply given to the air with no heating idea affiliated with this statement. It appears that experiences with draughts were employed here. It is an important finding that most students who recognized that heating took place did not connect it with an energy transformation or with the loss of energy of the pendulum. The heating was merely seen as an outcome of the friction.

Students' ideas concerning whether heat energy may be transformed into kinetic energy were also very limited. If explanations were given, the emphasis was on the concrete mechanisms facilitating the transformation and not on energy considerations (see similar findings in Fedra, 1989).

3.5 Students' conceptions of temperature equalization

In problems 1 to 3 students' conceptions of temperature equalization are thoroughly investigated. A great majority of students in all three problems was of the opinion that the temperatures of the bodies involved are equalized, i.e. that the bodies will have the same temperatures at the end of the processes (in problem 1: 29 students out of 34; in problem 2: 24 out of 34; in problem 3: 25 out of 28). But 18 out of our 34 students (i.e. 53 %) used "alternative" conceptions in at least one problem, i.e. were of the opinion that temperature differences may remain or occur after equalization. The temperature differences which may

remain or occur after equalization are, however, usually small ones.

The most frequent reason given for temperature differences was different qualities of the materials in interaction. 15 out of 34 students in problems 1 and 2 (where different materials were in interaction) gave this reason at least once. The ideas why different materials are of influence were above all these:

- * The ease with which heat enters or leaves different materials varies.
- * Different materials attract heat or retain heat differently.
- * The particles are variously close to one another, they have different qualities (e.g. different inertia or speed).

There is another interesting concept as to why temperature differences may occur. 6 students were of the opinion that the process of temperature change may keep going in the same direction even after temperature equalization due to heat inertia. Here an analogy with the oscillations of mechanical bodies was apparently employed.

Although the great majority of our students arrived at the same conclusion as physics (namely that temperatures of bodies in thermal interaction will become the same) the framework on which this conviction was based is far from the physics one. These frameworks have been outlined above, especially in 3.2 and in 3.4. The responses reveal some uncertainty as to what is equalized, temperature, heat or energy. This may result, for instance, in the idea that two bodies have the same energy or heat if the temperatures are the same. An indication of this insufficient distinction between heat, energy and temperature is the idea of energy balance which rests on the idea that bodies of the same temperatures have the same energy. This idea was, for instance, employed by students to explain why nothing happens when alcohol and water of the same temperature are brought into contact (problem 5.2): the temperatures are the same, hence the energy is the same, hence the tendency to cause an effect is the same, hence no temperature changes occur.

Students' attempts to make sense of the presented temperature equalization processes differ from those of physicists also in the following aspect. Where the situation of problem 1 is concerned, for instance, physics focuses on the interaction between the hot metal and the cold water, i.e. on the interaction of the bodies which are in direct contact. Interactions between these bodies and the surroundings are neglected at first. In contrast it is striking that several students did not even view this process explicitly as an interaction process.

There are also some remarkable "alternative" conceptualisations of the temperature equalization process. Some students appeared not to be aware that every cooling process requires for an interaction partner. It appears that they held the idea that bodies may cool spontaneously without other bodies being involved.

3.6 Students' conceptions of irreversibility

The findings presented so far form the basis of the following summary of our findings concerning students' conceptions of irreversibility. Two irreversible processes are involved in this study, namely temperature equalization (heat conduction) and a pendulum's oscillations dying out after some time.

3.6.1 Irreversibility of temperature equalization

As has been reported above most of our students did not think that the temperature equalization process may be spontaneously reversed, i.e. they did not think that temperature differences may occur by themselves (cold tea, for instance, never heats up by itself by cooling its surroundings; see problem 4). Most students therefore were aware that temperature equalization is an irreversible process. Viewing this aspect of irreversibility as "self evident" thus appears to be justified, as approaches to the second law in lower grades usually do (see e.g. Haber-Schaim, 1981; Duit, 1983b). However our study has revealed that this idea of irreversibility is not rooted in a physics framework but in very different everyday ones.

Within the framework of heat as intensity (see 3.2.1) which is opposed to the physics one irreversibility is an idea which is certainly near at hand. A temperature difference which would occur by itself would require differences in intensities to occur by themselves. This is an idea which is rejected by most students. It is interesting that some students explained this by pointing to the idea that nothing can be created from nothing. This is an argument which is commonly seen as an indication of the conservation of extensive quantities like substance or energy. But here it is used to support the idea of irreversibility.

The idea that intensities tend to equalize and may not occur by themselves appears to be the prevailing idea underlying students' conceptions of irreversibility. Most students viewed temperature as an intensive quantity and hence irreversibility was somewhat self evident for most students. Of course, this idea basically fits into the physics framework, but here it was based on a framework which is much vaguer where distinguishing between extensive and intensive aspects is concerned.

3.6.2 Irreversibility of the pendulum's oscillations

Here too most students did not have the idea that the process may be reversed by itself, i.e. that the pendulum may start oscillating by itself by cooling the surrounding air. But the framework on which this correct conviction (from the physics point of view) is based is far from the physics one. It is mainly simply the idea that something of this kind does not happen. Most students did not learn physics conceptions which would facilitate a deeper understanding of their conviction. A prerequisite for the understanding of the irreversibility of the pendulum's motion which almost no students hold, for example, is the idea of transformation of heat energy to motion energy

3.6.3 Irreversibility as general feature of all processes

In the concluding problem of the interview (problem 8) we wanted to find out whether students are aware that processes always run

by themselves in one direction only. Here the findings are even more basic in nature than the ones presented above because there was not enough time in the interview to discuss this issue in sufficient detail. The discussion turned out to be rather difficult because what is meant by "by itself" had to be clarified as did "directions of processes". Here most students were also of the opinion that processes occur in one direction only (23 out of the 27 we asked this question). But the frameworks students employed in their attempts to make sense of their opinions were the ones mentioned above, i.e. were far from physics concepts.

A "Cause-effect-thinking" was dominant. The cause of the process which occurs in a natural direction is "inherent in nature"; if the process is reversed the cause has to be arranged in some way. A stone, for instance, falls due to gravity (it is in the nature of the stone to fall), it will not go back to the initial height, because the cause - here an upward force - is missing. It is interesting that processes were not seen as interactions here either and were not viewed in terms of energy balances.

That processes occur in one direction only was explained sometimes in a somewhat teleological framework: processes aim at specific states, e.g. at the state of equalization or rest. Analogies from daily life behavior were employed to explain why processes are not reversible: they cannot be reversed because it is pointless to work against ones own aims and intentions.

4. LEARNING BASIC ASPECTS OF THE SECOND LAW - CONCLUSIONS WHICH MAY BE DRAWN FROM THE FINDINGS OF THIS STUDY

In this study our aim is to gather information which may be used to design new approaches to teaching and to learning basic aspects of the second law of thermodynamics. In particular our study was guided by the two questions which are used as the headings of the following paragraphs 4.1 and 4.2.

4.1 Do students learn basic aspects of the second law during traditional physics instruction?

Our study is restricted to a few of the basic aspects of the second law listed in fig. 1. It focuses on irreversibility and also gives some attention to energy degradation and the tendency towards disorder. The answer our study provides to the question in the title of this paragraph is clearly negative. Where irreversibility and energy degradation are concerned most students were convinced that processes occur in one direction only and that energy is "used up". But these ideas were mainly based on intuitive everyday conceptions and were not based on the physics framework taught in school. Where the tendency towards disorder is concerned students' ideas about the particle model in school were very limited. An understanding of irreversibility in terms of the tendency towards disorder cannot therefore be expected.

4.2 Do conceptions students gained during traditional physics instruction form a fruitful starting point for teaching and learning basic aspects of the second law?

The answer provided by our study to the second research question is also clearly negative. What is known from many other studies, that several years of physics instruction often develop students' everyday conceptions towards the physics ones only in a rather limited way became clear. Three main limitations have been discussed in the preceding chapter.

Firstly, at the end of four years of physics instruction which gave considerable attention to the concepts of heat and temperature an adequate distinction between heat and temperature did not result. It is striking that almost no student in our study used the concepts of heat and temperature consistently in all of the problems in the physics way. Quite a lot of students did not develop any distinction except that they viewed temperature as a measure of heat. If one compares our findings concerning the distinction between heat and temperature after several years of physics instruction with findings from other studies before instruction there appear to be no considerable differences. The

everyday conception of heat (which does indeed have many facets) still appears to be prevalent.

Secondly, students' conceptions of energy are very limited. Most students appear to be almost unable to conceptualize processes in the framework of the physics energy concept. The conception of energy as the cause of actions and effects is prevalent. Ideas concerning energy transformation and conservation are not well developed. The idea that a certain quantity, namely energy, changes appearances during processes, but does not change amounts, is seldom employed. The qualities which different energy forms have in common are stated as follows: all energy forms are able to bring about effects, different energy forms bring about different effects (e.g. heat energy heats bodies, kinetic energy sets or keeps bodies in motion). The principle of energy conservation is often mentioned by the students in the interviews as an important aspect of energy but it is not interpreted in the physics framework but in the students "cause effect" framework. Viewed in this framework energy is not lost in a process because an effect (e.g. heating a body or lifting a weight) was caused. Ideas of energy degradation are usually of an everyday idea type: energy is used (or used up) when effects or actions are brought about. Degradation ideas based on a conservation frame (which is the case with the physics energy degradation idea) are rarely to be found.

Thirdly, the particle model was used only by a very limited number of students. Physics ideas also appear not to be prevalent among those who used it. A tendency to disorder ideas on the basis of the particle model is presented by only 4 students.

We think that we cannot avoid coming to the conclusion that the physics instruction our students received was not able to provide a fruitful starting point for teaching and learning basic aspects of the second law. The conceptual frameworks students gained are so far from the physics frameworks that learning of basic aspects on the basis of these conceptual frameworks appears to be rather unlikely. This conclusion is also valid for

the basic aspects mentioned in fig. 1 which were not investigated in the study because an understanding of them is also required for a sound conceptual framework concerning heat, temperature, energy and the particle model.

4.3 Consequences for teaching and learning about basic aspects of the second law

The conclusion to be drawn from this study is not that basic aspects of the second law are too difficult to understand in lower grades. But it became obvious that it is indeed difficult to learn them, in the same way as it is difficult to learn the concepts of temperature, heat and energy and the particle model.

The conclusion to be drawn is that a mere enlargement of traditional physics teaching by aspects of the second law will not be successful because traditional teaching does not result in sound students' conceptual frameworks in the area of heat and energy. To teach basic aspects in lower grades will only be possible within a totally new approach to heat and energy in which these aspects are integrated. We think that our in depth analysis of students' attempts to make sense of the phenomena presented in the interview point to major learning difficulties and hence will be of value when new approaches are designed.

4.4 Concluding remark

At the outset we pointed out that the study presented here is an initial attempt at getting to know students' conceptions in an area where not much research is available. We think that the study did indeed enlarge our knowledge in this field. But further studies are necessary. The findings of our in-depth interview analysis should be verified with other groups of students and a development of new approaches to the areas of heat and temperature in which aspects of the second law are integrated are necessary in order to provide a basis for studies on students' conceptual change from their everyday conceptions to the physics ones. There are considerable difficulties where carrying out such studies is concerned. They have to be very wide in

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scope because quite a substantial range of concepts is involved which only can be taught over a longer period of time and not in a few lessons.

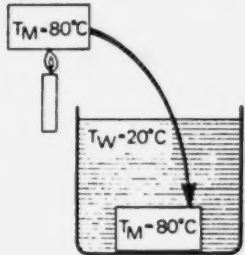
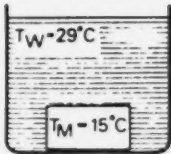
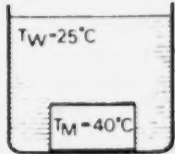
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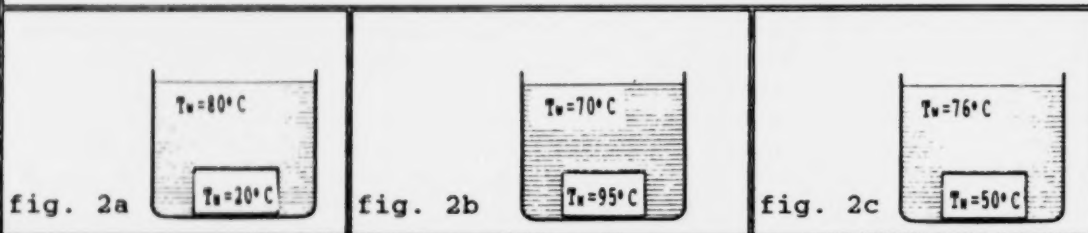
6. APPENDIX : THE PROBLEMS OF THE INTERVIEW

In the following the problems used in the interview are presented. In the boxes an abbreviated version of the interview guide we used is given. The questions asked are printed in italics. The figures were presented to students on cards during the interview.

1. A hot piece of metal is put into cold water	
1.1 A piece of metal is heated to 80°C. It is then put into water of 20°C. <i>What happens?</i> If the student predicts a temperature difference at the end of the process: <i>What happens then?</i>	 fig. 1a
1.2 If the student uses the terms heat and temperature in 1.1.: <i>What do you mean when you speak about heat/temperature? What has heat to do with temperature?</i>	
1.3 Some students carried out this experiment and got different results. Some of them are correct, others are not. One group, for instance, presented this result: after a while the temperature of the water is 29°C and the temperature of the piece of metal 15°C (fig. 1b). <i>What do you think about this result? Is it possible? Why/why not?</i>	 fig. 1b
1.4 Imagine the piece of metal has a temperature of 27°C and is put into water of also 27°C. <i>Is it possible that after some time the temperature of the water is 29°C and the temperature of the piece of metal is 15°C? Why/ Why not?</i>	
1.5 Here are the results from another group of students who carried out the experiment in 1.1: they say that temperatures equalize (say at 27°C) but that after equalization the piece of metal becomes warmer, and the water becomes colder. After a while the piece of metal has a temperature of 40°C, the water a temperature of 25°C (fig. 1c). <i>Is this result possible? Why/why not?</i>	 fig. 1c

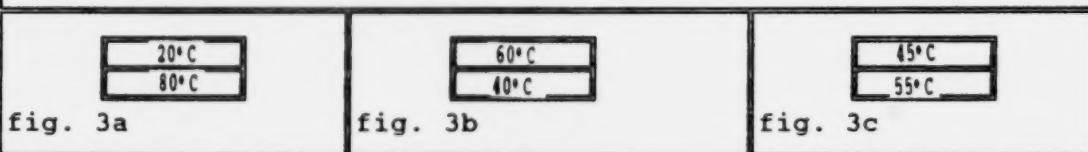
2. A cold piece of metal is put into hot water

Here a piece of metal at 20°C is put into water at 80°C . In principle the interview follows the same sequence of questions as in 1.1, 1.3 and 1.5. The situations presented are given in fig. 2a, 2b, 2c.



3. Two metal plates are brought into contact

The heat exchange/temperature equalization of two metal plates is discussed. The interview follows the same succession of questions as in 1.1, 1.3 and 1.5. The situations presented are given in fig. 3a, 3b, 3c.



4. Does tea heat up again by itself after it has cooled?

4.1 You put hot tea on your desk. You leave the room. After about ten minutes you come back.
What has happened to the tea? Why?
Is there any change of the air temperature?

4.2 Imagine there is a cup of tea at room temperature. You leave the room for a while. When you return the tea has become warm.
Is this possible? Why? Why is only the reverse process possible? Did the surroundings receive heat (energy) when the tea cooled down? If so, why does the surroundings not give this heat back (energy) to the tea?



fig. 4a

5. Heating of water and alcohol

- 5.1 There are two identical containers filled with equal amounts of water and alcohol at 20°C. Tom heats them with two equal burners. After 2 minutes the temperature of the alcohol is 30°C, the water has this temperature after 4 minutes.

Please explain this.

What do you think? Has one of the liquids got more heat (energy)?

Has one of the liquids stored more heat (energy)?

water

20° C

alco-
hol

20° C

fig. 5a

- 5.2 What happens, when Tom brings the two containers with alcohol and water both of 30°C into contact?

Do the two temperatures stay the same? Why/why not?

water

30° C

alco-
hol

30° C

fig. 5b

- 5.3 Tom has the following idea: I shall use water at 30°C to heat alcohol at 20°C. The water has got a great deal of heat energy. If I bring the water and alcohol containers in contact then the alcohol will heat up to 40°C and the water will cool down to 20°C.

What do you think about Tom's idea?

water

30° C

alco-
hol

20° C

water

20° C

alco-
hol

40° C

fig. 5c

6. Heat never travels from the cold to the hot

In some textbooks you may find this sentence:

"Heat never travels by itself from a cold body to a warmer one".

What does this sentence mean to you?

Please give examples to support the statement.

Please give examples which are not in accordance with it. Has the sentence something to do with the processes discussed in the previous problems?

What is the meaning of "by itself" in the sentence?

Are there conditions in which heat may travel from a cold body to a hot body?

7. Does a pendulum start swinging by itself?

7.1 Here is a pendulum. It is hanging on a string. It does not move. Suddenly it starts moving and oscillates more and more.
Is this possible? Why/ why not?

7.2 Well, let us have a look at the normal behavior of a pendulum. We set it moving.
What does happen then? Why?
Are there any changes somewhere when the oscillations become smaller and smaller?



fig. 7a

7.3 *Is energy linked with the processes discussed?*
Does the pendulum have energy? What form of energy?
What happens to the pendulum's energy when the oscillations become smaller and smaller? Does it disappear?
Where does it go to?
Is there any heating associated with the process?

7.4 Ok, let us come back to pendulum starting moving "by itself" (7.1).
What would be necessary so that the pendulum starts oscillating?
Is it possible for the pendulum to remove heat energy from the surroundings and starts moving? Why/why not?
Does the surrounding air contain any heat/energy?
Is it possible to start the pendulum movement by heating it with a burner?
How is it possible to transform heat into motion? Why is this not a possible way of setting the pendulum in motion?

7.5 What does energy mean to you? Has energy anything to do with heat?
What do you mean when you say that heat is a form of energy? What is the difference between heat energy and other forms of energy? What are the concurrent aspects of the different forms of energy?
If heat is a form of energy then shouldn't it be possible to set the pendulum into motion by using heat?

8. Processes occur in one direction only

8.1 *Have you realized that there is something all the problems have in common?*

8.2 *All of the problems had to do with the fact that processes occur by themselves in one direction only (Interviewer gives three examples; examples from problems 1 and 7 and distribution of ink in water). Please give other examples for processes which occur by themselves in one direction only!*

8.3 *What about processes around you? Do they occur in one direction only? Or are there processes which can occur forwards and in reverse? Do you have any idea why processes occur by themselves in one direction only? Is it possible to reverse them?*